ANGULAR ERROR IN ULTRASOUND DOPPLER TISSUE VELOCITIES AND ITS IFLUENCE ON THE DERIVED VARIABLE PEAK SYSTOLIC STRAIN

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Abstract- **When recording velocities using ultrasound Doppler, the obtained velocities are always a projection of the true velocities onto the direction from the recording point towards the transducer. In this study we have marked up lines in sequences of ultrasound images of the heart showing the direction of the original velocity. Doing this, it is possible to calculate the original velocity in the marked direction. Both the recorded and corrected velocities have been used for calculating strain, in order to compare the two. Apical ultrasound images have been recorded on a sample of 18 normal individuals. The corrected velocities are on the average less than 5% higher than the recorded ones, and the effect on the derived variable strain is even less, so we suggest that the correction can be omitted when recording tissue velocities through an apical window.**
Keywords **– Echocardiography, Doppler, angular error, angle dependency, strain, strain rate, tissue velocity**

I. INTRODUCTION

When recording velocities using ultrasound Doppler techniques, the velocity obtained is a projection of the true velocity vector on the line from the recording point to the transducer [1]. This causes an error, which increases with increasing angle for the direction of the true velocity. This error in turn affects other derived variables, such as strain rates [2] and strain.

To make it possible to correct this, one must know the original direction of the velocity. When seeing the heart as a dynamic displacement pump [3], one can recognize the main direction of the myocardial motion as being longitudinal. When marking up the longitudinal direction in the ultrasound picture, it is possible to calculate the original velocities from the recorded ones.

Both two- and four-chamber apical images have been recorded on a sample of 18 normal individuals. The study of tissue velocities in the myocard using an apical window may seem narrow, but this is in fact frequently used for the investigation of myocardial performance [4-6], as well as derived variables calculated using data acquired this way [7]. Thus both corrected and non-corrected velocities have been used for calculating strain, as peak systolic strain is an easily calculated variable. This has been taken as an example to show how the angular correction can affect derived variables.

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II. METHODOLOGY

A. Raw data

The raw data consisted of both two- and four-chamber sequences of ultrasound images recorded through an apical window on 18 normal individuals. A GE Vingmed System V machine has been used. Each sequence is recorded over two consecutive heartbeats acquired at rest at end expiratory apnea. An averaging over the two heartbeats has been done.

B. Extracting velocities and directions

Velocities have been extracted at six points in three pairs in each heart wall, enumerated 1-6 starting from apex towards the base as shown in fig. 1. The walls are the septal and lateral walls displayed in a four-chamber image, and anterior and posterior walls shown in a two-chamber view. All points are chosen between the apex and the atrio-ventricular (AV) plane. The reason for choosing points in pairs is that a constant, known distance between two points is needed when calculating strain. The distances 1 to 2, 3 to 4 and 5 to 6 are all 15 mm.

The main direction of the velocities is as earlier mentioned believed to be longitudinal, and so the velocities have been corrected towards the lines marked up in black in fig. 1.

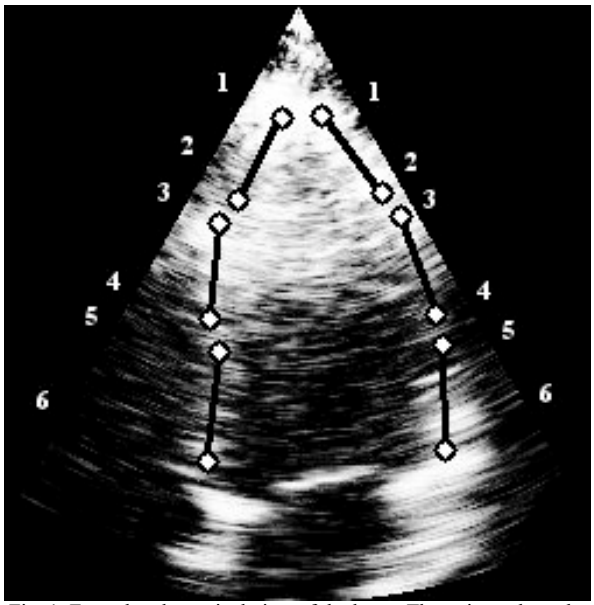

Fig. 1. Four chamber apical view of the heart. The points where the velocities are measured are marked up as black and white circles, enumerated from the apex towards the base. Black lines show the segments where strain has been calculated.

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Abstract

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C. Angular correction

The angles between the line noting the direction of the true velocity and the ultrasound beams are schematically drawn in fig. 2. The figure shows clearly that the angles will not be equal
for the different points. The recorded velocities is a projection of the true velocity onto the line pointing from the point of interest towards the transducer, and a velocity recorded in e.g. point 2 of fig. 2 will back-projected to the line 1-2 by the equation

$$\vec{v}_c = \vec{v} / \cos\phi \quad (1)$$

where v denotes the original, recorded velocity and v_c the corrected velocity. As the cosine of ϕ is a number between 0 and 1, the corrected velocity v_c will be larger than the recorded one.

We do not have any accurate information about the lateral placement of the points within the ultrasound beams, they are approximated to lie in the center of the beam. As a result of this, two points lying within the same beam will both be seen as on the center of the same beam, which will cause the line between them to be parallel to the beam. In this case there will be no angular correction. This will happen for the points 3 and 4 of fig. 2.

D. Calculating peak systolic strain

Strain is a measure of the displacement. To calculate it we first calculate an estimate of the strain rate (also known as strain velocity) [8], which is the speed at which the myocard is deforming. The strain rate ($d\varepsilon/dt$) is estimated by [9]:

$$\hat{\dot{\varepsilon}} = \frac{v(r+L) - v}{L} \quad (2)$$

where v is the velocity in the points r and $r+L$ and L denotes the offset, the distance between the two points where the velocity is measured. L is in this case always 15 mm.

The result, the strain rate, is integrated over time to calculate the strain. The unit of strain rate is s^{-1}, hence its integral over time will be dimensionless. The value of strain is thus usually given in percent, which is the unit used throughout this paper.

Over a heartbeat, starting from the R-peak of the ECG, the strain of the left ventricle will start at zero, decrease until it reaches its minimum value at end systole and increase back to zero. This is because the strain rate is negative when the myocard is contracting, as it is during systole, and positive during the diastolic relaxation. The peak systolic strain, which is the lowest point of the strain curve, is chosen as variable for comparison, as it is easily extractable.

The integration of the strain rate is subject to some drift. This has been corrected for. When assuming that the drift is linear, and knowing that the myocard comes back to its initial position after one heartbeat in normal individuals, it is an easy task creating an algorithm which removes this drift.

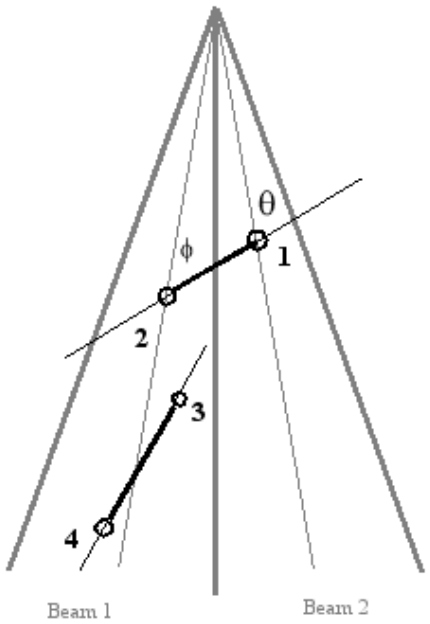

Fig. 2. Schematic view of two ultrasound beams (gray) with their center lines. Within the beams the points 1, 2, 3 and 4 are marked. The line between 1 and 2 goes over more than one beam, and so the angles θ and ϕ between the line 1-2 and the centers of the beams will not be equal. The points 3 and 4 lies within one beam, and the angle between the line 3-4 and the center of the beam will be set to 0°.

III. Results

A. Obtained angles

All obtained angles are referenced in Table I with their means and standard deviations. High values for the standard deviation reflects the high amount of 0° angles. As previously mentioned two points falling within the same beam will result in the angles being 0°.

How much higher the corrected velocities are than the recorded ones, is shown in percent in Table II. The reason why Table I and Table II not immediately seem to correspond is that when calculating Table II we first calculated the differences in percent, then calculated the mean value of these.

The average of the overall increase in the corrected velocities, all measured points seen together, was 4.37±14.8% within a 95% confidence interval.

TABLE I
THE MEANS AND STANDARD DEVIATIONS OF THE ANGLES OBTAINED FOR THE DIFFERENT WALLS FROM THE APEX TOWARDS THE BASE.

	μ(°) / σ(°)			
Position	Septal	Lateral	Anterior	Posterior
Apical, 1	11.8 / 11.3	11.2 / 7.80	9.69 / 10.2	10.2 / 14.6
2	8.51 / 8.40	7.77 / 5.55	7.05 / 7.63	7.22 / 11.2
3	17.3 / 13.8	5.50 / 9.39	14.4 / 12.4	2.27 / 9.65
4	13.9 / 11.2	4.44 / 7.67	11.6 / 9.91	1.86 / 7.89
5	16.2 / 15.6	15.8 / 15.3	12.9 / 15.5	12.3 / 14.5
Basal, 6	13.6 / 13.2	13.5 / 13.1	10.8 / 13.0	10.3 / 12.1
All points	13.6 / 12.5	9.70 / 10.9	11.1 / 11.7	7.36 / 12.3

TABLE II
THE MEAN AND STANDARD DEVIATION OF HOW MUCH HIGHER THE CORRECTED VELOCITIES (v_c) ARE THAN THE RECORDED ONES (v) BASED ON THE RATIO $(v_c-v)/v$.

	μ(%) / σ(%)			
Position	Septal	Lateral	Anterior	Posterior
Apical, 1	4.33 / 5.65	2.89 / 2.43	3.18 / 5.11	6.61 / 19.1
2	2.22 / 3.05	1.39 / 1.23	1.68 / 2.88	3.23 / 9.89
3	8.29 / 8.36	1.85 / 3.53	5.88 / 5.95	1.80 / 7.64
4	5.19 / 5.38	1.20 / 2.39	3.66 / 3.59	1.10 / 4.68
5	8.66/ 10.4	8.26 / 9.57	6.98 / 9.88	6.03 / 7.85
Basal, 6	5.93/ 7.05	5.79 / 6.73	4.69 / 6.58	1.04 / 5.12
All points	5.77 / 7.23	3.56 / 5.71	4.35 / 6.21	3.80 / 10.2

B.Comparing corrected and non-corrected values

To evaluate the importance of the angular correction performed on the velocities, we compared strain values calculated using the original, recorded velocity with values obtained using corrected velocities. The result of this is shown in the Bland-Altman plot of fig. 3. This plot includes all measurements for all walls. When drawing Bland-Altman plots for each wall or for each segment, the results were similar, so only the overall result is presented here.

What we see is that a lot of the points are close to zero. Actually the bias is only 0.0141%± 2.28%, meaning that the strain calculated using the angular correction has a value that is on the average 0.0141% higher than the non-corrected strain (remember that % is the unit of strain). This is not significantly different from 0 according to the two-tailed Student *t*-test.

IV. DISCUSSION

A. Poor lateral resolution

As mentioned in section II, the angles towards which the velocities should be corrected are 0° when the points defining the line fall within the same beam. The maximum error introduced by this will occur when the furthermost point lies at the end of one beam, such as when point 4 in fig. 2 lies at the end of the leftmost part of beam 1 and point 3 at the rightmost part of beam 1. The maximum length of a beam is 14 cm, but as the points are always placed between the AV-plane and the apex, the maximum distance from the transducer to the furthermost point is 10 cm. The angular increment from beam to beam is at most 6.0° and the distance between two points such as 3 and 4 is always 15 mm. The angle between 3-4 and the leftmost and rightmost parts of the beam will in this case be 38° and 44° respectively. This means that the corrected velocity should be 27% and 39% respectively higher than the recorded one.

For the points where the line between them crosses more than one beam, one can assume that over- and underestimation of the angle due to the unspecific lateral information will cancel each other out in the long run.
Anyhow, trying to define the lateral placement of these points will be construction of information that we do not really have. As the velocity information is not laterally more specific, we can also not be more specific when marking up the points.

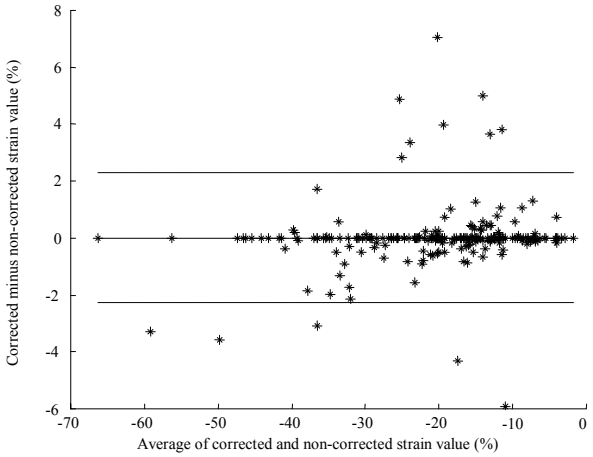

Fig. 3 Bland-Altman plot of the strain values with angular correction towards the ones without correction. Solid line shows the mean and dashed lines show 1.96 times the standard deviation, 0.0141% ± 2.28%.

B. Sources of error

There are many other sources of error than the Doppler velocities being a projection of the true velocity onto the direction towards the transducer when calculating the myocardial strain. First of all the beams recording the velocities are wide, so the velocity data is not very exact. We only assume that the main direction of the true velocities are longitudinal, and after doing that assumption, there will be errors when drawing by hand the line that marks up the longitudinal direction.

There are also internal errors within the ultrasound machine, such as filters limiting the maximum and minimum velocities when recording tissue velocities. The moving tissue must be separated from blood and stationary tissue, and the filtering techniques for doing this are not always exact.

When studying the peak systolic strain there is also the problem of integration drift.

C. Specificity

This study only considers tissue velocities recorded on the myocard using an apical window, and results are only applicable to velocities recorded the same way. The results can not be used to draw general conclusions about velocities recorded using ultrasound Doppler techniques.

V. CONCLUSION

The angular correction leads to an increase in velocity lower than 5%. When keeping in mind that there are a lot of other error sources than just the Doppler velocities being a projection of the real velocities onto the direction towards the transducer, we suggest that the angular correction for tissue velocities recorded using an apical window can be omitted.

The influence of the angular correction on the derived variable peak systolic strain was shown to be not significantly different from 0, so one can clearly spare oneself the trouble of performing the angular correction when investigating strain in an apical window.

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